Unsteady Base Pressure Measurements in the Near Wake of a Cylinder With Imposed Three-Dimensional Disturbances

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Abstract

The effects of geometrically imposed three-dimensional disturbances that were introduced by a spanwise-periodic trailing-edge splitter plate on the instantaneous base pressure of a circular cylinder were investigated. Measurements indicate a direct coupling to the shedding frequency between the stagnation-line and base-pressure signals. A low frequency component in the base pressure power spectra was found and was directly related to the irregular shedding observed in the wake.

Introduction

It has been previously shown by Roshko [1,2] that the vortex shedding structure can be altered by the introduction of a splitter plate in the near wake of a circular cylinder. A splitter plate has the effect of modifying the region of absolute instability behind a bluff body and in some cases was observed to either enhance or attenuate vortex strength, Roshko[1] and Gerrard [3]. Use of splitter plates delays any direct interaction between the two opposing shear layers and lengthens the regions behind the body before vortices are fully formed, Apelt & Isaacs [4], Apelt, West & Szewczyk [5], Igarashi [6], Unal & Rockwell [7]. A comparison of the measurements in the wake of a circular cylinder with a two-dimensional straight splitter plate to those with a spanwise-periodic trailing-edge splitter plate, Pearson & Szewczyk [8], indicates a variation in wake width, formation length and vortex shedding modes. The present investigation was undertaken to study the effects of a spanwise-periodic trailing-edge splitter plate on the instantaneous fluctuating base pressures.

Experimental Arrangement

All of the experiments were conducted in the University of Notre Dame 61cm. square test section open circuit wind tunnel with a maximum speed of 35 m/s and turbulence intensity of less than 0.1 %. The inlet was 152 cm. and had a 24:1 contraction.

The model was a 5.1 cm. diameter aluminum circular cylinder with a groove along the wake centerline to accommodate a splitter plate. Experiments were performed on two-dimensional splitter plates of varying length as well as spanwise-periodic trailing-edge splitter plates of varying length, amplitude and wavelength. All splitter plates were 1.6 mm thick. The two-dimensional plates had length to diameter ratios of $\ell/D = 0.125, 0.5, 0.625, 1.0, 1.5$ and 2.0. Spanwise-periodic trailing-edge splitter plates of varying plate length, $\ell/D = 0.625, 1, 2$, and constant amplitude and wavelength, $a/D = 0.5$ and $\lambda/D = 3$ respectively, as well as varying amplitude, $a/D = 0.5, 0.875, 1.875$, and constant plate length and wavelength, $\ell/D = 2$ and $\lambda/D=3$ respectively were studied. Peaks and valleys were designated as the splitter plate positions with the most downstream and upstream trailing edge respectively. End plates were used in all experiments and had a 2.5 aspect ratio as recommended by Stansby [9]. The end plates were slotted to accommodate a splitter plate and mounted such that the length-to-diameter ratio was 8.

The model was equipped with flush mounted pressure transducers along the stagnation line and in the base region, at 170 degrees relative to the stagnation line, see Fig. 1. Calibrated pressure transducers had a range of 0-10 inches of H_2O, a sensitivity of 5mv/in H_2O, a frequency response of 50 kHz and a linear response up to 2.5 kPa.

The shedding characteristics from the model were detected with a hot-wire probe using a TSI Flow Analyzer IFA-100. Data acquisition of velocity and pressure signals as well as control of a three-dimensional traverse unit for the probe was performed through a Macintosh IIfx computer with LABView hardware and software. The system had the capability of sampling eight simultaneous signals at a rate of 250 kHz per channel.

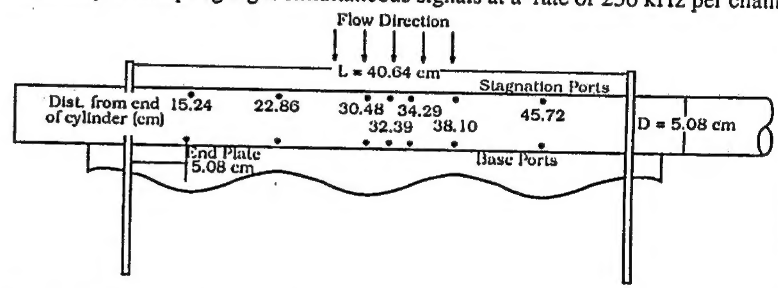

Fig. 1. Cylinder transducer configuration.

Experimental Results

Tests were conducted at Reynolds number of 30,000 in the wind tunnel and with model described above. Unsteady pressure measurements were made at several spanwise locations along the stagnation line and in the base region. Long time averages of the pressure signals were found to be in good agreement with other mean pressure measurements previously reported by Apelt et al.[4, 5] for two dimensional splitter plates and by Pearson &Szewczyk [8] for spanwise-periodic trailing-edge splitter plates.

Selected simultaneously sampled fluctuating base pressure signals acquired from transducers on the cylinder for a spanwise-periodic trailing-edge splitter plate ℓ/D=1.0,

a/D=0.5, and λ/D=3.0 and equivalent two-dimensional splitter plates ℓ/D=0.5 and 1.0 are shown in Fig. 2. The transducers are located at the same spanwise positions that correspond to a location of a peak and valley for the periodic splitter plate for all splitter plate configurations. Several observations can be made about the features of the fluctuating pressures. Stagnation-line pressure traces, Figs. 2(a-c), were correlated at the shedding frequency, 38.3 Hz and were always in phase with each other. Spanwise base pressure signals from peak and valley locations Figs. 2(d-i), reveal a strong correlation with the shedding frequency and were always in phase except for phase reversals shown in the Figs. 2(d-i). For the equivalent two-dimensional splitter plates, Figs. 2(f-i) similar phase reversals were also observed. These measurements indicate a direct coupling to the shedding frequency between the stagnation-line and base pressure signals as was observed by Mangalam & Kubendran [9] for a plain circular cylinder. However, no direct feedback of the non-regular phase reversals indicated in Figs. 2(d-i) was found in the stagnation-line pressure signals. For ℓ/D=0.625 the stagnation-line peak and valley pressure signals were found to be 180^o out of phase with the base pressure signals at the same spanwise location.

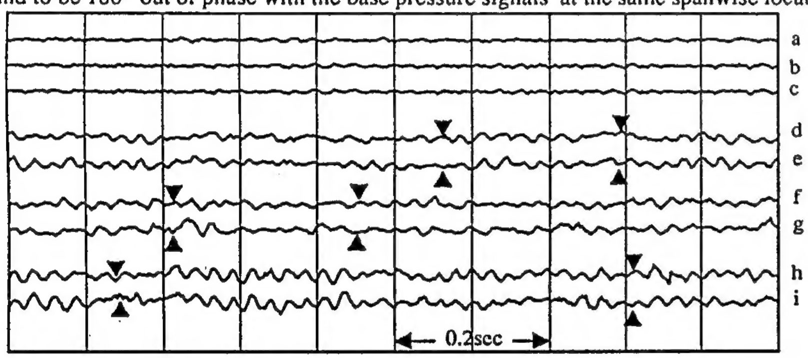

Fig. 2. Simultaneously sampled fluctuating pressure signals at peak and valley locations. A-c) Stagnation pressures. D&e) Base pressures for spanwise-periodic trailing-edge splitter plate. F-i) Base pressures for equivalent two-dimensional splitter plates.

The spectral content of the signals indicated a dominant frequency of 38.3 Hz with a number of peaks around the shedding frequency as shown in Fig. 3b (j-l) for the pressure traces shown in Fig. 2d, 2f, & 2i respectively. The differences in frequency in the peaks around the shedding frequency show up as a low frequency component, 2-5 Hz, in the power spectrum shown in Fig. 3a. Since these are long-time average spectra the peaks in the spectra indicate that the shedding is not regular and different modes of shedding occur in time. As a result the flow exhibits some inherent three-dimensional effects in the shedding process. The results from the pressure measurements low frequency content in the power spectra and irregular shedding, agree with the hot-wire measurements and flow visualization observations of Pearson & Szewczyk[8].

Correlation between peak and valley base pressure signals and hot-wire signals at the peak, valley and mid-point spanwise location both inside and outside the wake was performed. Correlation's inside the wake indicate a phase lag of approximately 90^o between the base pressure and hot-wire signals equivalent to the spatial separation of the two signals divided by the convection velocity of the flow for all spanwise locations. Signals from the hot-wire outside the wake were fully correlated to the shedding frequency and indicated no phase lag at any of the spanwise locations.

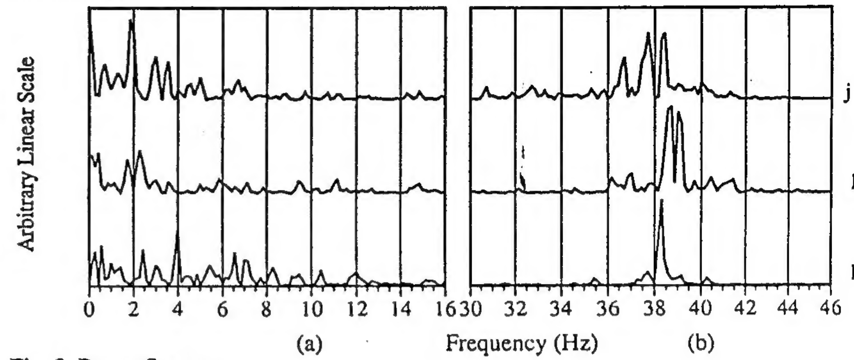

Fig. 3. Power Spectra.

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